

FEASIBILITY STUDY OF BAMBOO DRUMSTICKS

by

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Table of Contents

Abstract.....	3
Introduction.....	4
Background.....	5
Literature Review.....	5
Bamboo in Composites.....	6
Sustainability.....	7
Drumstick Manufacturing.....	8
Problem: Waste.....	8
The Anatomy of a Drumstick.....	8
Mechanical Issues with Bamboo.....	9
Design Solution: Radial Lamination.....	10
Methodology: Prototype Machining.....	10
Methodology: Prototype Testing.....	11
Results.....	12
Recommendations.....	12
Economic Analysis.....	13
Conclusion.....	14
Bibliography.....	15
Appendix.....	17-18

Abstract

This project is a study on the feasibility of introducing bamboo as an alternative material for the application of drumsticks. The American drumstick industry has been historically very stable and robust due to its commitment to high quality. This high quality comes at the price of large amounts of waste that is largely burned to provide facility heating. With the recent push for corporate responsibility of the total life cycle of their products and the push for increased sustainability, bamboo was considered as a viable resource as a partial alternative or complete replacement. Prototypes of the bamboo drumsticks were fabricated using a technique discussed as radial lamination to increase overall stiffness which is crucial to a drumstick's functionality and an economic analysis was conducted.

It was concluded that the overall prospect of using bamboo as an alternative to hickory or conventional hardwoods for drumsticks, even with the production cost increase of employing radial lamination, is economically and environmentally feasible.

Introduction

The American drumstick manufacturing industry historically has been and continues today to be a steady and healthy industry feeling less impact than other industries by the recent national economic downturn and holding the large majority share of the global drumstick market despite overseas competition. It is because of the overwhelming amount of engineering and quality control that has allowed American companies such as Vic Firth and Pro-Mark to be so pervasive in this global market. But because these high quality standards, a large amount of waste is produced resulting in not only higher costs, but also a lower level of sustainability.

This project is a feasibility study on the prospect of using bamboo (which is much more sustainable in more ways than one) instead of the hardwoods currently used (mainly hickory) for this large market. There are certain issues with using bamboo as a substitute for a drumstick:

- Bamboo lacks lateral stiffness to provide a necessary energy rebound.
- Certain species of bamboo lack dimensional geometry (wall thickness) for drumsticks.

This project will test a experimental method of construction that provides a solution to both of the above issues. This method will be referred to as *radial lamination*. As part of the project, the following will be accomplished:

- Several prototypes will be produced and will be tested by a panel of seasoned drummers.

- The prototypes will also be pitch-tested. (This is a common quality check where the stick is struck on a surface and the principle frequency of the stick is captured and used as a sorting index. All high-quality sticks are pitch-paired.)

- Finally, recommendations on process design for mass production and a cost estimate will be made, especially to determine if the increased machining required for radial lamination would be offset by the savings in cost of bamboo.

Background

There are over 1400 globally recognized species of bamboo [Nijhuis, 2009] (1250 reported species from booshootgardens.com) each with their own unique characteristics in terms of rate of maturity, structural properties and applications. Although bamboo is typically used as a hardwood substitute it is actually a type of grass. Bamboo has been used in countless applications in history from bookmaking to scaffolding and house building to today's new experimental applications of using bamboo fibers as reinforcement material in aluminum and PLA composites [Tokoro, 2007]. Since the recent concern for sustainability and uses of renewable resources, bamboo has been the center of much research as a viable substitute for a range of materials since a large variety bamboo matures in 1/10th of the time it takes to mature most hardwoods. Along with the overarching mechanical advantages of bamboo, it is this alarming growth rate that presents the largest prospective advantage in terms of cost and sustainability.

Literature Review

Table 1: Amada, 1999

Literature regarding bamboo is spread out in terms of industries, applications, and research. There were several articles and journals focused on the mechanical properties of bamboo. One such journal looked at the physical, chemical and mechanical characteristics of bamboo and also its feasibility and

Measured fracture toughness of bamboo

Materials	K_{IC} (MPa m ^{1/2})
Bamboo: culm (maximum value)	116.2
Bamboo: culm (average value)	56.8
Bamboo: node	18.4
Steel	217
Al-Alloy	33
Douglass fir	1.64
Spruce	7.0

performance as a fiber material in MDF [Li, 2004]. The prospect of bamboo as a biomass resource was investigated but it was concluded that use of bamboo as a biomass would not be a significant improvement over current biomasses [Scurlock, 2000].

One article written in 1999 by Shigeyasu Amada focused on the fracture properties of bamboo finding that on the whole, bamboo had more favorable properties than most common hardwoods and that fracture characteristics varied with what section of the bamboo was being tested. Other articles investigated characteristics such as abrasion wear [Chand, 2004], thermal conductivity in bamboo PLA composites [Takagi, 2007] and the finite element analysis of bamboo to investigate bamboo's viability as a functionally graded material.

A new machining technology called peel grinding was also included in the literature research as a promising method of machining bamboo, especially a certain type of peel grinding called pinch grinding. In general, peel grinding is a process where a small grinding wheel, CBN being the increasingly popular choice, is used essentially as a turning tool. The wheel is very narrow, typically 5mm or smaller, and operates at speeds up to 250m/sec along with part rotational speeds of up to 7,500 rpm,[Tooling and Production, 2007].

Robert Aronson, senior editor of Manufacturing Engineering outlines the advantages of

peel grinding:

- “Dramatically reduced cycle time.
- Combined operations.
- Decreased throughput time. Only software needs to be changed to accommodate different parts, as opposed to tooling changes.
- Ability to grind dissimilar metals on one platform.
- Complex shapes can be formed without a profile wheel. The thin wheel functions like a single-point cutting tool under CNC control. Therefore it's simple to change profiles without changing wheels.[Aronson, 2006]

□ ccording to Maruer, peel grinding is an effective process for meeting high-volume-part runs because of its high mrr and wheel speed, which is usually from 100 to 180m/sec. As the wheel speed increases substantially, the grinding forces and corresponding heat are reduced exponentially.[Richter, 2004]

Since the two primary machining methods of drumstick manufacture are turning and centerless grinding, both processes having their unique advantages and disadvantages, peel grinding seems to be a process where disadvantages of both are eliminated and advantages unique to peel grinding provide promising prospects.

Bamboo in Composites

The structure of bamboo is a naturally occurring composite of the bamboo matrix with bamboo fibers that run longitudinal to the bamboo stalk and discrete nodes distributed along the the length of the stalk. While bamboo is a naturally occurring composite, the excellent mechanical properties of the longitudinal bamboo fibers have become of special interest in the use of synthetic composites, especially since bamboo is so inexpensive. A study on bamboo as an effective material in the use of composite boat hull manufacturing was completed in this past year [Corradi, 2009]. As mentioned above, the application of chopped bamboo fibers as a fiber reinforcement material for a PLA composite [Tokoro, 2007] has been realized and shows much promise especially in today's global climate towards sustainability and renewable resources. Another interesting departure in composite materials is the application of a bamboo aluminum composite material in which reformed bamboo is sandwiched between two sheets of aluminum and impregnated with resin.

Bamboo is a renewable natural source and abundantly available. It is cheaper than wood and aluminum alloy. So reformed bamboo is cheap enough to be a prospective potential substitute for some industrial aluminum alloy. The thin aluminum sheet will protect the epoxy resin from ultraviolet rays and the reformed bamboo from corrosion, while the re-formed bamboo can strengthen the aluminum and reduce the total weight of the material. Besides its mechanical properties, the overwhelming advantage of the new material is its low cost compared with industrial aluminum alloy; in our experiment, the cost is only two-thirds that of aluminum. While the performance, density and price are considered simultaneously, the ratio of a material's performance to its price and density is a comprehensive criterion. We found that the ratio of tensile strength to density and price was increased by 717.2% [Li, 1994].

Sustainability

Bamboo, the fastest growing plant on earth, is commonly seen as a green material. According to its supporters, bamboo's fast growth means it sequesters more carbon than slower-growing trees, thus qualifying the flooring and plywood for a "rapidly renewable" materials accreditation under the Leadership in Energy and Environmental Design (LEED) green building rating system [see "MisLEEDing?" by Daniel Brook; SCIENTIFIC AMERICAN EARTH 3.0, Vol. 18, No. 4; 2008]. According to an article from *Horticulture Week*:

Growing requirements are quite easily met. There are no specific soil requirements - bamboo should perform well in any reasonably fertile medium. They are also generally shallow-rooted, and will therefore pose little risk to drains or other street features. They perform well for land-stabilization projects [Holland, 2008].

Bamboo requires less energy and land area to grow than most other hardwoods that require an average of 30 years to mature, depending on the species. Although most species of bamboo reach maturity between 3-5 years, most of its growth occurs during the first year [Bajzek, 2009]. Bamboo functions very well as a carbon dioxide scrubber, sequestering 4 times more CO₂ and 35% more oxygen than hardwood trees. There is currently a special interest in the Mississippi Delta as a location to plant millions of acres of bamboo to revitalize the local and national economy. This is now possible because while it normally takes 60-100 years to propagate bamboo from seedlings, CEO Jakie Heinricher has developed a method of cloning mature bamboo which completely sidesteps the century long propagation phase and makes it possible to produce millions of bamboo plants [boosshootgardens.com].

Drumstick Manufacturing

Currently, the two most predominant manufacturing methods are turning and centerless grinding. Vic Firth uses the centerless grinding process while Pro-Mark uses a tracing lathe for a majority of the machining. Both companies have been in business since the 1960's and continue to hold considerable market shares in the drumstick industry.

Vic Firth's main manufacturing facility, located in Maine, receives hickory timber and immediately cuts it into rough square dowels in preparation for the kiln operation. The dowels are placed in the kiln for two weeks with close attention to the temperature and humidity of the inventory to control the moisture content until the dowels reach 6-8% moisture level. This percentage is measured using a pin meter, which is a device that has two pins an inch apart driven into the length of a sample dowel and the resistance between the two pins are measured and a moisture percentage is calculated. Residual stress in the timber is tested by making cuts along the grain at the ends of the dowel to see if the cut sections deflect due to residual internal stresses. The rough dowels are then cut into a square dowel with specific dimensions that will allow the doweling machine to machine the square dowel into a round dowel. At this point a laser indicator is used to measure the runout. The dowels are then fed into two centerless grinders. The first grinder machines the butt end, the second machines the tip profile. Then sticks are then lacquered, stamped with the company logo and model designation, pitch paired and then packaged [www.vicfirth.com].

Pro-Mark's main facility is located in Houston, Texas with a over-seas facility where their Shira Kashi Oak sticks are manufactured in Japan. The main differences in methods of manufacture between Pro-Mark and Vic Firth are that Pro-Mark uses a tracing lathe to turn the round hickory dowel into the final profile. The turning operation leaves excess wood on either ends of the stick which are removed in following operations. Pro-Mark uses a proprietary material to finish most of their sticks though twenty models have a no-lacquer, natural finish. Pro-Mark states that 100% of the finishing materials are consumed in the finishing process resulting in zero waste.

Problem: Waste

Pro-Mark averages a 5-7% defect rate [Pat Brown, Pro-Mark rep.] and Vic Firth reports producing 12,000,000 sticks annually. A reporting on Vic Firth's defect rate could not be found and Pro-Mark's production volume was only disclosed to be in the millions. Therefore assuming Vic Firth's production volume with Pro-Mark's defect rate yields 600,000-840,000 defects found along the production line. This does not reflect the weight of material lost during machining (approximately 45% of stock material is lost). Both



Illustration 1: Taken from www.vicfirth.com

companies completely recycle these defects, either turning them into sawdust (used in morgues) or burning the waste to heat the facilities.

The Anatomy of a Drumstick

Because of the nature drumming and virtuosity of current professional artists, decades of time and engineering have been spent on designing the right drumstick for the job. Seasoned drummers develop incredibly precise reflexes allowing them the speed and precision to practice their art [see *Jojo Mayer* in Multimedia Appendix], but it also demands more from the quality of the stick itself and differences undetectable to a novice drummer are felt to be worlds apart in the hands of a veteran.

-Feel: The second most important aspect of a drumstick next to sound would be described simply as feel. This designation is largely unhelpful to an engineer. Usually what is meant by feel is how the stick sounds and responds when struck against a head of a drum. There are several factors that largely affect the interaction between the surface of the stick and the drumhead. The first is the shape of the tip. The shape of the tip is critical in the interaction between the stick and the surface hit (drumhead or cymbal). A perfectly round tip (typical in marching snare and rock sticks) would ensure a perfectly normal return energy

vector relative to the drumhead, but also results in a different sound quality or timbre than an oval shaped tip (typical with jazz style sticks). The model chosen for the bamboo prototype (Vic Firth's American Hickory 5A) of this project has teardrop profile which is effectively a hybrid of the oval and spherical tip shapes which gives an all around, general purpose stick suitable for a wide range of musical styles.

-Material: The second factor is stick material, particularly the material's stiffness and hardness. These aspects are especially important as they are significant contributors to the amount of energy return which results in a stick rebound enabling what is known to trained drummers as the free stroke. It is this stick rebound or free stroke that allows drummers to play very quickly with relative ease. This rebound is also a large component to the feel of a stick. The stick rebound provides a tactical feedback to the drummer by which he/she assesses the quality of the hit. A lower amount of stick rebound might result in the stick feeling slow or unresponsive.

-Weight: The third factor is weight, which is directly related to density and moisture content. A heavier stick will produce more volume from the drumhead and cymbal, but will require more energy to produce the same amount of stick rebound in a lighter stick. Sticks that are too heavy may result in injury to the drummer.

-Geometry: The fourth factor that will be discussed in this work will be the basic geometry of the stick itself. The length and taper of the stick affect the sweet spot at which the drummer positions the thumb and index finger (or middle finger) to form the fulcrum of the stick. This sweet spot is typically 1behind the center of gravity of the stick. Drummers have found that forming the fulcrum 1behind the center of gravity allows for maximum control for minimum effort. In other words, holding the stick at this particular spot allows for the most efficient and natural stroke, requiring the least amount of force from the fingers and wrists. This spot is also key because it allows for the greatest amount of stick rebound.

Mechanical Issues With Bamboo

Compared to most hardwoods, bamboo's mechanical properties are for the most part superior. Coupled with bamboo's sustainability and low cost, bamboo would seem to be a viable substitute or even replacement of the use of currently used hardwoods such as hickory, maple and shira kashi oak. The largest three largest issues with using bamboo as material for drumsticks is dimensional thickness, fiber orientation and stiffness. Typical drumstick diameters range from .450- .60while bamboo wall thicknesses vary largely in range, moso bamboo the most common species of bamboo, has walls typically .5 While this may be sufficient for certain sizes of sticks, the longitudinal fibers in the sticks are distributed unevenly across the cross-section which would cause the stick to have a different response depending on the axial orientation. The other issue with bamboo is that while bamboo has incredible longitudinal yield strength, the lateral stiffness is significantly less than that of hickory or other hardwoods. Lateral stiffness is crucial in drumming as the stiffness directly

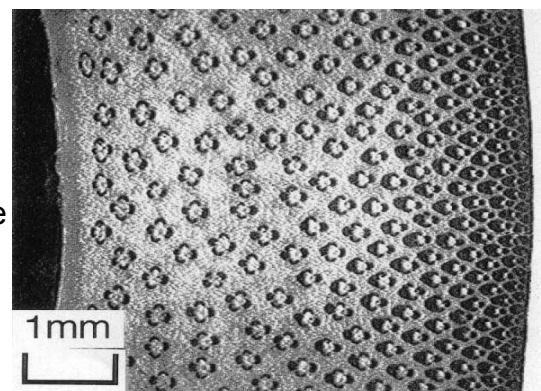
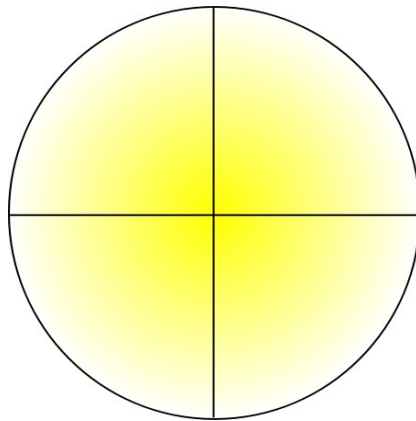


Illustration 2: Bamboo Cross Section
[Amada, 1999]

relates to the amount of rebound and feedback when striking the drumhead.

Design Solution: Radial Lamination



*Illustration 3: Radial Lamination
Cross Section*

The solution to the large issues of bamboo was radial lamination. Instead of machining a single piece of material, four smaller pieces of material would be joined together in an axially symmetric array. This design limits deflection of the individual pieces, increasing overall stiffness. Using smaller dowels limits the amount of variation in radial fiber distribution and provides a means to control the orientation of the distribution.

Additional advantages of using smaller dowels in the radial lamination are the increased capability of quality control and the reduction of waste. As mentioned above, internal stresses in the hickory dowels were found by making section cuts at the ends of the dowel. Starting with smaller dowels allows warping and stress defects to be easily detected at the early stages of production. Since radial lamination provides a degree of mechanical support from the glue, the smaller, individual dowels can be allowed to have a certain amount of deflection, reducing the number of dowels rejected and wasted.

This solution requires more machining and therefore would be more expensive in terms of gluing and cycle time. But lower cost of bamboo makes an increase in machining costs more viable and economically justifiable.

Methodology: Prototype Machining

Turning the prototypes was the most viable and ideal option based on what was available. At first the Haas SL-20 was chosen to turn the prototypes, but since severe damage might be caused in the enclosed cage to the ways and moving parts by bamboo particles coming in contact with the oil and expanding, it was decided that the TL-1 would be a safer choice. An added benefit to this choice was found in the tailstock. The SL-20's tailstock is hydraulic with the lowest amount of clamping force at 50 lb, which would most likely split the dowel. The TL-1's tailstock is completely manual, allowing for complete control over clamping. Its open layout and slower rapid movements allowed for safe placement of a vacuum hose by the cutting tool to minimize bamboo particle deposition, reducing potential damage. The CAD/CAM model was built from data pulled from the SmartScope Flash 250 vision system in the IME metrology lab in order to accurately reproduce the profile of a Vic Firth American Classic 5A stick. PRO/E and Pro Manufacture were used to generate the G-Code for the TL-1.

The tool holder used for turning the prototypes was the MVJNR 16-30, chosen for its large back-angle and small nose radius required to fit into the deep groove at the tip end. Though a tool holder with a positive rake would have been more ideal to reduce cutting forces, no such tool was found in the advanced machining lab with the same dimensions of the MVJNR 16-30. Since no data on surface speeds of bamboo were found, an experiment was conducted to find an appropriate feedrate (approx. 15 ipm) for the TL-1's 2000 rpm

maximum spindle speed.

Moso bamboo is the most commonly used bamboo a number of different applications which also makes it the most readily available. The only source of moso bamboo dowels that was found came from www.mastergardenproducts.com which only had bamboo dowels available in 3/8 diameter. The dowels were received in 48 lengths. The Vic Firth model stick is 16 in length, so in order to reduce waste and produce as many prototypes as possible, the prototype was shortened to 15 so that three dowel quarters could be taken from the 48 dowel. 1/16 was removed from two adjacent sides of the dowels to form perpendicular surfaces for the gluing surfaces. Gorilla Glue, a polyurethane glue, was used at the suggestion of Ladd Caine, Master Lab Technician for the IME labs. The prototypes were wrapped to prevent expansion and left to cure overnight. After curing, the laminated dowels were machined on the TL-1. In order to securely hold the workpieces and locate the center, a collet holder was used in place of the three-jaw chuck. The first operation turned the butt end profile and 11 of the stick. This operation required use of a dead center in the tail stock to reduce deflection. The second operation turned the tip profile and remaining 4 of the stick.

Methodology: Prototype Testing

-Field Test: The primary test for the prototypes consisted of a field test by a small panel of seasoned drummers each having at least 20 years of drumming experience. They were asked to test the drumsticks and fill out a questionnaire (see Appendix) to evaluate the feel and response of the stick.

-Pitch Testing: Each stick was pitch tested. Using a USB microphone and an instrument tuning program Pitch Perfect, which captures an input signal from the microphone and outputs the principle frequency of the signal, each prototype was struck on a control surface at the stick's shoulder and the data was collected.

-Runout, Weight and Dimensions: Each prototype stick was measured at the tip, base of the shoulder and butt end and the data was recorded. Each prototype's weight was measured on a digital scale and each runout was measured using a lathe and dial indicator.

Results

It was reported that within 30 minutes of field testing, the polyurethane glue began splitting at the tip of the stick and produced a dead sound that negatively effected both the sound quality of the stick and the response. The other major criticism of the prototypes was their weight. Where a hickory stick weighs an average of 1.7 oz., the prototype sticks weighed an average of 1.03 oz.

One successful outcome was found in the absence of criticism: stick rebound. The radial lamination design was chosen to increase lateral stiffness which is lacking in raw bamboo. The quality of rebound was not an explicit criterion on the questionnaire to test whether there was any noticeable distinction in the amount of rebound in the prototypes. Since there were no explicit criticisms of the amount of rebound, the implication is that there was a comparable amount of rebound in the prototypes in regard to hickory sticks.

Testing showed that the pitch varied by 10 hertz (see Appendix A) which is much smaller than the range of frequencies that Vic Firth sorts their sticks into (100 Hz range). In a subjective test where the prototypes were struck against a wooden table at the tip, different

timbres were produced depending on the quadrant struck the table. This was due to the difference in density and hardness (node vs. internodes) of the bamboo at the tip area of the stick. This issue might be eliminated with the use of nylon tips and/or dowel orientation prior to gluing to have similar density sections at the tip.

Vic Firth's production line has a wide range (12 +) of weight classifications that are 2 grams apart from each other. The total range in weights in the prototypes was only .2 ounces or 5.67 grams, only 3 weight classifications by Vic Firth's standards. If the prototypes are indicative of large scale production levels, this would suggest a sharp decrease in weight variance and overall a more consistent product that could reduce waste. Since drumsticks are sold in pitch and weight paired pairs, if one stick breaks, the odds of finding a stick of similar weight and pitch are very slim and so, most drummers dispose of both sticks. One drumstick company is addressing the issue by selling stick in sets of 3 so that when one breaks, an alternate weight and pitch paired stick is available without having to throw away the set of two and purchasing another pair, reducing a considerable amount of waste. If there is less variance in pitches and weights in the products themselves, the selling of sets of 3 becomes much easier.

Recommendations

While Pro-Mark's main machining process is turning, the process requires three operations immediately after turning to remove excess wood before sanding and lacquering/painting. While Vic Firth's centerless grinding only requires two operations and cuts the sanding operation out, at least two sets of large grinding wheels are required for each of the 400 models of drumsticks. This translates to large tooling, setup and inventory costs and a lack of flexibility.

A relatively new technology that is widely popular in Europe and recently gaining interest in America is a machining process called peel grinding. In peel grinding, a small diameter (30-40cm) grinding wheel is used as a turning tool would be used. ..peel grinding is an effective process for meeting high-volume-part runs because of its high mrr and wheel speed, which is usually from 100 to 180m/sec. As the wheel speed increases substantially, the grinding forces and corresponding heat are reduced exponentially.[Richter, 2004] Pinch grinding is peel grinding with the use of two grinding wheels on opposite sides of the part to eliminate deflection and allow roughing and finishing in a single pass. With CNC pinch grinding, the best of both worlds in regards to turning and centerless grinding meet. Surface finishes of centerless grinding are achieved perhaps even without the use of coolant and the flexibility of turning is simplified to a matter of switching programs. Plus with the lack of deflection, lower cutting forces and higher mrr's, lower cycle times on top of the already reduced setup times can be realized. With the falling prices of CBN wheels, costs in tooling stand to be reduced as well, especially since CBN wheels can typically cut 100,000 *metal* parts before replacement. Currently, peel grinders cost anywhere between \$500,000 to \$1,000,000 [Richter, 2004], therefore the largest cost consideration would be in the initial costs of the machine(s).

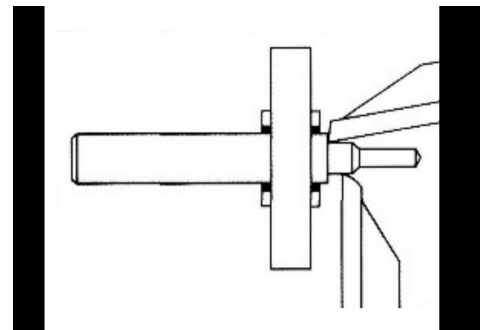


Illustration 4: Taken from "The Powerful Potential of Peel Grinding" Aronson, 2006

Since testing showed that the polyurethane glue was not strong enough to withstand the impact forces at the tip of the prototypes, the possibility of using epoxy should be explored. The use of epoxy would result in a leaner production environment, eliminating the need for an overnight curing station and WIP inventory. Also since the weight of the prototypes were unsatisfactory, other species of bamboo should be considered as a replacement for the moso species to better match the weight of hickory sticks.

Economic Analysis (See Appendix)

The economic analysis was focused on the implementation of a pinch grinding station to a pre-existing drumstick manufacturing company, therefore, pre-existing equipment (molders, dowelers, finishing equipment and quality checks) were not accounted for. Since it is unlikely that hickory would be completely phased out of production initially (or perhaps never) due to a strong adherence to tradition, the economic and investment analysis was done based on an annual production volume of 4 million sticks instead of 12 million. Since bamboo is in high demand for a wide variety of industries, most, if not all, of the bamboo waste produced could be sold or given away for waste upcycling. Since there is no current market price for bamboo scrap, this was not included in the economic analysis.

The \$4.40 quote for a 10' long 3dia. stalk of bamboo came from bamboo supplier in California. This amount of material could be used to produce 177 dowel quarters which translates to 44 sticks per stalk which breaks down to \$.1 of direct material cost per stick, not including the cost of epoxy (the gluing operation should be automated). The potential profit margin was not based off of a certain percentage, but based off of the current wholesale price of Vic Firth sticks to obtain a direct comparison between the two. Assuming the bamboo would arrive in uncut stalks, the price of 5 hydraulic bamboo splitters were included along with additional molders to save from resetting existing molders to the smaller dowel size and to preserve tooling life of the pre-existing molders as the outer skin of bamboo is much harder than hickory. A rough estimate for a fixture to aid in the application and hold for the 60 second curing time of the epoxy was also included.

For a production volume of 4 million sticks per year, a minimum of 5 pinch grinders would be required, assuming production times of 8 hours per day, 6 days per week and 50 weeks per year with a unit cycle time of 10 seconds. That would require 5 bar feeders and at least 5 gluing fixtures to reduce bottlenecking and facilitate dovetailing (while the pinch grinder runs, the 80 second total cycle time for the 10' stalk could be used to glue the next 10' section). Finishing and inspection costs were estimated in the unit cost, but excluded from the initial investment analysis.

The analysis resulted in a total annual investment of just under \$4 million dollars assuming an estimated 17% rate for taxes, shipping and initial setup. If the bamboo sticks were sold at the current average price of hickory sticks (\$9), the difference in generated revenue (difference in wholesale prices between bamboo and hickory) would be \$5,088,000 per year, thus the cost of investment would be recovered within the same year of implementation.

Conclusion

This is the most ideal time to be considering the implementation of large scale bamboo

product manufacturing. With the cloning technology that has enabled the rapid production and reproduction of bamboo and the ability to grow it domestically, bamboo could be a significant source of domestic GDP. This prospect coupled with the fact that Vic Firth and other American companies have consistently dominated the global market of this bread and butter industry creates a very potent mix of profit potential, economic revival, and environmental amelioration. The tests results from this project have shown that building drumsticks with radial lamination from bamboo exhibit a reduction of variance in pitch and weight resulting in a more consistent product. With this decrease in variance, the next level of quality control and process design can be reached. It is this commitment to quality that has put American companies in the dominant position of drumstick manufacturing despite economic downturns and oversea competition. The cost savings of using bamboo along with the possibility of selling and upcycling bamboo waste only serves to bolster this dominance and increase feasibility. The major factor in the feasibility of this project now rests on the American and local Mississippi governments agreeing to convert the land to bamboo farms, but with the current deforestation rate of bamboo in Asia, domestic bamboo is a very real possibility.

Bibliography

- Amada, Shigeyasu and Sun Untao. Fracture Properties of Bamboo. Elsevier Science Ltd. Jul. 1999.
- Aronson, Robert. The Powerful Potential of Peel Grinding. Manufacturing Engineering. Feb. 2006: 136-2.
- Bajzek, Nick. Bamboo Overview. Professional Builder. Apr. 2009:74-04.
- Chand, Navin and U. K. Dwivedi. High stress abrasive wear study on bamboo. Journal of Materials Processing Technology. Oct. 2004.
- "Green shoots or bamboo shoots?".E&MJ: Engineering & Mining Journal. 2009: 210-80.
- Holland, Dave. Bamboo. Horticulture Week. Oct. 2008: pg.18.
- Li, S.H., S.Y. Fu, B. L. Zhou, Q. Y. Zeng, X. R. Bao. Reformed bamboo and reformed bamboo/aluminium composite. Journal of Materials Science. Apr. 1994.
- Li, Xiaobo. Physical, Chemical, and Mechanical Properties of Bamboo and Its Utilization Potential For Fiberboard Manufacturing. Louisiana State U. May. 2004.
- Nijhuis, Michelle. "Bamboo boom." Scientific American Earth 3.0. Summer. 2009: 19-02.
- "Peel grinder offers advantages that go beyond hard turning. Tooling and Production. Jun. 2007. <www.toolingandproduction.com>
- Richter, Alan. Peel Out. Cutting Tool Engineering Magazine. Sept. 2004: 56-09.
- Silva, Emilio Carlos, Matthew Walters, and Glaucio Paulino. "Modeling Bamboo as a Functionally Graded Material: Lessons for the Analysis of Affordable Materials." Journal of Materials Science, 41.21 (2006): 6991-7004.
- Silva, Emilio Carlos Nelli, Matthew Walters, and Glaucio Paulino. "Modeling Bamboo as a Functionally Graded Material." *AIP Conference Proceedings*, 973.1 (2008): 754-759.
- Takagi, Hitoshi, Shuhei Kako, Koji Kusano, and Akiharu Ousaka. "Thermal Conductivity of PLA-bamboo Fiber Composites." Advanced Composite Materials. 2007: 16-4.
- Tokoro, R. , Vu, D. , Okubo, K. , Tanaka, T. , Fujii, T. , et al. . "How to improve mechanical properties of polylactic acid with bamboo fibers." Journal of Materials Science, 2008:43-2.
- Scurlock, J.M.O., D.C. Dayton, B. Hames. Bamboo: an overlooked biomass resource?. Biomass & Energy. Jan. 2000.

Appendix A: Prototype Data

Prototype #	Tip dia.	Butt End dia.	Middle dia.	Shoulder dia.	Pitch (Hz)	Weight (oz)
1	0.391	0.563	0.563	0.547	306	1.1
2	0.391	0.563	0.547	0.563	307	1.1
3	0.391	0.563	0.547	0.547	304	1
4	0.391	0.563	0.547	0.563	308	1.1
5	0.391	0.547	0.547	0.547	304	1
6	0.391	0.547	0.547	0.547	311	1
7	0.391	0.547	0.547	0.547	304	1.1
8	0.391	0.563	0.547	0.547	304	0.9
9	0.391	0.563	0.563	0.547	301	1
Mean	0.391	0.557	0.55	0.55	305.444	1.033

Appendix B: Bamboo Drumstick Routing Sheet

Operation #	Description	Cycle Time (hr)	Direct Material(\$)	Direct Labor Rate	Total Cost
10	Split raw stalk using hydraulic bamboo splitter	0.006	\$0.10	\$10.00	\$0.16
20	Square dowels using the molder	0.006	\$0.00	\$10.00	\$0.06
30	Apply epoxy	0.017	\$0.11	\$10.00	\$0.28
40	Pinch grinding	0.003	\$0.00	\$20.00	\$0.06
50	Laser runout check	0.001	\$0.00	\$0.00	\$0.00
60	Injection Mold Tip	0.002	\$0.02	\$10.00	\$0.04
70	Lacquer/Paint*	1	\$0.10	\$0.17	\$0.27
80	Pitch Pairing	0.001	\$0.00	\$0.00	\$0.00
90	Packaging	0.002	\$0.05	\$10.00	\$0.07
Total Unit Cost					\$0.94
+200% Overhead:					\$1.88

*Labor rate split over batch of 60 sticks

Appendix C: Investment Analysis

Material Investment	
Annual Production Volume:	4000000
Number of sticks per stalk	44
Number of stalks for APV:	90909.091
Price per stalk (10' long 3" dia.):	\$4.40

Total Cost of Bamboo APV: \$400,000.00

Amount of epoxy per stick (oz):	0.25
Ounces per gallon:	128
Number of sticks per gallon:	512
Number of gallons per APV:	7812.5
Price per gallon of epoxy:	\$50.00

Total Cost of Epoxy APV: \$390,625.00

Unit Cost:	\$1.88
Cost of Unit Pair:	\$3.76

Avg. price of hic. Sticks:	\$9.00
Profit Margins (30%):	0.3
Hickory Unit Cost	\$6.30

Profit Difference:	\$2.54
APV (Pairs):	2000000
Increase in Annual Revenue:	\$5,088,000.00

Machinery Investment	Cost per Unit	# of Units	Total Cost
Bamboo Splitter	\$2,000.00	5	\$10,000.00
Molder	\$2,000.00	2	\$4,000.00
Gluing fixture	\$2,000.00	5	\$10,000.00
Bar Feeder	\$14,000.00	5	\$70,000.00
Pinch Grinder	\$500,000.00	5	\$2,500,000.00

Total Machinery Invest.: \$2,594,000.00

Investment Sub Total:	\$3,384,625.00
Taxes, Shipping, Setup	1.17
Grand Total 1 st year:	\$3,960,011.25